Effects of Soil Selenium (Se) Content and Exogenous Se Supplementation on Crop Se Content

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Abstract [**Objectives**] This study was conducted to investigate the effects of soil selenium (Se) content and exogenous Se supplementation on crop Se levels and provide a theoretical basis for the production of Se-enriched agricultural products. [**Methods**] Thirty three representative townships in Xiayi County, Ningling County, and Yongcheng City were selected. Soil Se content and its impact on wheat Se level were measured. The effects of exogenous Se supplementation on the Se content of crops including soybean, wheat, peanut, corn, sweet potato, grape, crisp pear and apple were also investigated. [**Results**] Showed that the soil Se content in 18 townships of Xiayi County ranged from 0.08 to 0.34 mg/kg, and Se-adequate areas, Se-deficient areas and severely Se-deficient areas accounted for 27.78%, 66.67%, and 0.055% of the total, respectively. In Ningling County, the soil Se content in 11 townships ranged from 0.13 to 0.23 mg/kg, and among them, Se-adequate areas and Se-deficient areas comprised 18.18% and 81.82%, respectively. In Yongcheng City, the soil Se content in 4 townships ranged from 0.16 to 0.23 mg/kg, and Se-adequate areas and Se-deficient areas constituted 75.00% and 25.00%, respectively. The soil Se content in 33 townships across Xiayi County, Ningling County, and Yongcheng City ranged from 0.07 to 0.34 mg/kg. However, the Se levels in wheat from all 33 townships fail to meet the standard for Se-enriched agricultural products. It indicates that relying solely on soil Se supply is insufficient for crops to achieve the Se level required for Se-enriched agricultural products. Exogenous Se supplementation could effectively increase the Se content in soybean, wheat, peanut, corn, sweet potato, grape, crisp pear, and apple. Among these, soybean, wheat and peanut showed the highest Se levels after supplementation, all exceeding 0.10 mg/kg and meeting the industry standard for Se-enriched agricultural products. [**Conclusions**] The results of this study indicates that exogenous Se supplementation can serve as a key measure for producing Se-enriched agricultural products.

Key words Exogenous Se; Soil; Crop; Se content

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Selenium (Se) is a crucial mineral element composed of 25 human selenoproteins, such as glutathione peroxidase. It is renowned as the "spark of life", "king of cancer prevention", and "guardian of the heart", offering benefits such as antioxidant effect, resistance to bacteria and viruses, and cancer prevention. As one of the essential mineral elements for human life, Se plays a vital role in maintaining the normal functioning of physiological processes. It is recognized as the third most important nutritional element after iodine and zinc. More than 70% of China's territory is classified as Se-deficient, making it one of the countries with a typical Se deficiency. This results in a severe inadequacy of Se intake in the diets of most Chinese residents[1]. The lack of Se can lead to various health issues, including cancer, cardiovascular and cerebrovascular diseases, and thyroid dysfunction[2].

The human body primarily obtains Se through food intake, particularly from plant-based sources. The total Se content in soil serves as the basis for crop absorption. Clarifying the relationship between total soil Se content and crop absorption levels is essential for gaining a deeper understanding of the mechanisms through which crops uptake Se, which, in turn, provides a scientific foundation for developing the Se-enriched functional agricultural product industry[3-5]. In this study, the relation between Se content in different types of soil and the corresponding Se levels in surface crops was investigated. Understanding the Se enrichment mechanisms in crops enables precise management of Se bioavailability through agronomic measures in real-world applications, and provides a theoretical basis for the production of selenium-enriched agricultural products.

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Materials and Methods

Sampling of different types of soil and their corresponding surface crops

We assessed the distribution of Se resources in the soil of Shangqiu area by reviewing relevant literature. Sampling of soil and surface crops was then conducted sequentially based on the natural Se content levels (high, medium, and low) of soil. The research team carried out field surveys and sample collection activities in key areas, including Ningling County, Yongcheng City, and Xiayi County, focusing on Se-rich resources. In each county or city, representative townships were selected for sampling. Specifically, measurements were conducted in 18 townships in Xiayi County, 11 townships in Ningling County, and 4 townships in Yongcheng City. Sampling Method: Within these three regions, villages were categorized sequentially into high, medium, and low Se content zones. For each village, 20 random sampling points were selected. At each sampling point, the "five-point sampling method" was applied to collect soil and surface crop samples.

Testing and analysis of collected samples

Through the survey and analysis, Se resource sampling was conducted in 33 villages across Ningling, Xiayi, and Yongcheng. The collected soil and wheat samples were subsequently tested.

Experimental design for artificial Se supplementation

By applying agricultural techniques such as Se-enriched foliar fertilizers to crops including wheat, corn, soybean, peanut, sweet potato, grape, crisp pear, and apple, the changes in Se content in the fruits or products of these crops were measured. Based on the differences in Se requirements per hectare for different crops, corresponding Se application rates, dilution ratios and application time were designed for wheat, corn, soybean, peanut, sweet potato, grape, crisp pear, and apple. The specific details are presented in the table below.

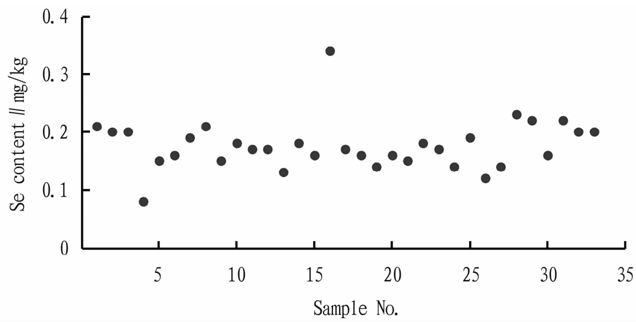
Table 1 Se application rates, dilution ratios and application periods for different crops

Crop	Application rate	Dilution ratio	Application period
Wheat	450 ml/hm^2	800	Booting stage, grain filling stage
Corn	750 ml/hm^2	800	Before tasseling and pollen shedding, grain filling stage
Soybean	750 ml/hm^2	800	Late flowering stage, pod/fruit setting stage
Peanut	750 ml/hm^2	800	Flowering and pegging stage, fruit expansion stage
Sweet potato	1 050 ml/hm^2	800	Tuber initiation stage, fruit expansion stage
Grape	1 500 ml/hm^2	800	Flowering stage, fruit setting stage, fruit expansion stage
Crisp pear	3 000 ml/hm^2	800	15 d after flowering, fruit expansion stage, one month before harvest
Apple	3 000 ml/hm^2	800	15 d after flowering, fruit expansion stage, one month before harvest

Results and Analysis

Analysis of soil Se content in parts of Shangqiu City

According to the national standard GB/T 44971-2024 *Soil Selenium Grade*, soil Se enrichment levels are classified into four gradients: Se-rich (Se content > 0.40 mg/kg), Se-adequate (0.20 – 0.40 mg/kg), Se-deficient (0.10 – 0.20 mg/kg), and severely Se-deficient (<0.10 mg/kg). According to Fig. 1, under the experimental conditions of this study, soil Se content was measured in 18 representative townships in Xiayi County. The soil Se content across these 18 townships ranged from 0.08 to 0.34 mg/kg. Specifically, 5 townships had Se levels above 0.2 mg/kg, classifying them as Se-adequate areas; 12 townships had Se levels between 0.1 and 0.2 mg/kg, classifying them as Se-deficient areas; and 1 township had a Se level of 0.07 mg/kg, below the 0.1 mg/kg threshold, classifying it as a severely Se-deficient area. Overall, in Se-adequate areas of Xiayi County, Se-adequate areas, Se-deficient areas and severely Se-deficient areas accounted for 27.78%, 66.67%, and 0.055% of the total, respectively. Based on measurements of soil Se content in 11 representative townships in Ningling County, the soil Se content across these 11 townships ranged from 0.13 to 0.23 mg/kg. Among them, 2 townships showed Se levels above 0.2 mg/kg, classifying them as Se-adequate areas, while 9 townships had Se levels between 0.13 and 0.19 mg/kg, classifying them as Se-deficient areas. Overall, in Ningling County, Se-adequate areas accounted for 18.18%, while Se-deficient areas made up 81.82%. Based on measurements of soil Se content in four representative townships in Yongcheng City, the soil Se content across these four townships ranged from 0.16 to 0.23 mg/kg. Among them, three townships had Se levels above 0.2 mg/kg, classifying them as selenium-adequate areas, while one township exhibited a Se level of 0.16 mg/kg, slightly below 0.2 mg/kg, representing a 20.00% decrease compared with 0.2 mg/kg, thus classifying it as a Se-deficient area. Overall, the majority of areas in Yongcheng City fell into the Se-adequate category, accounting for 75.00%, while a minority were classified as slightly Se-deficient, making up 25.00%. Based on the distribution of Se content, the ranking was as follows: Yongcheng City > Xiayi County > Ningling County. The vast majority of soil resources in these regions showed Se levels falling within the range of Se-adequate to Se-deficient.

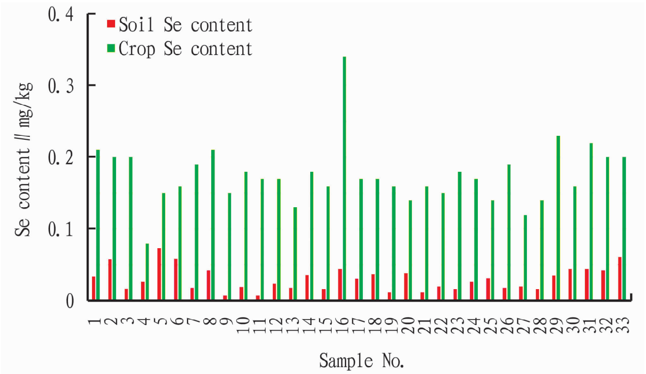


Samples 1 – 18: Xiayi; samples 19 – 29: Ningling; samples 30 – 33: Yongcheng.

Fig. 1 Soil Se content in Se-rich areas of Shangqiu City

Impact of soil Se content on wheat Se level

As shown in Fig. 2, the soil Se content across 33 townships in Xiayi County, Ningling County, and Yongcheng City ranged from 0.07 to 0.34 mg/kg, and the corresponding wheat Se content ranged from 0.01 to 0.065 mg/kg. In specific, the soil Se content in 18 townships of Xiayi County ranged from 0.08 to 0.34 mg/kg, with corresponding wheat Se levels ranging from 0.01 to 0.065 mg/kg. In the 11 townships of Ningling County, the soil Se content was between 0.13 and 0.23 mg/kg, and the corresponding wheat Se levels ranged from 0.01 to 0.045 mg/kg. In the 4 townships of Yongcheng City, the soil Se content fell within 0.16 to 0.23 mg/kg, with corresponding wheat Se levels ranging from 0.02 to 0.06 mg/kg. Notably, the wheat Se content in Yongcheng City was relatively higher. According to the industry standard GH/T 1135-2024 *Selenium-enriched Agricultural Products*, the specified Se content range for Se-enriched agricultural products is 0.10 – 0.15 mg/kg[6]. It is evident that the Se content in wheat from all 33 townships in Xiayi County, Ningling County, and Yongcheng City fails to meet the standard for Se-enriched agricultural products. It indicates that relying solely on soil Se supply is insufficient to achieve Se enrichment in agricultural products.



Samples 1 – 18: Xiayi; samples 19 – 29: Ningling; samples 30 – 33: Yongcheng.

Fig. 2 Impact of soil Se content on wheat Se level

Table 2 Impact of exogenous Se supplementation on crop Se content

Crop	Se content // mg/kg		Increase compared with the CK (times)
	Se spraying	Free of Se spraying	
Wheat	0.790	0.034	23.2
Corn	0.074	0.017	4.3
Soybean	0.830	0.032	25.9
Peanut	0.250	0.007 6	32.9
Sweet potato	0.058	–	–
Grape	0.050	0.002	25.0
Crisp pear	0.068	–	–
Apple	0.020	–	–

" – " indicates not detected.

Impact of exogenous Se Supplementation on crop Se content

As shown in Table 2, exogenous Se supplementation differentially affected the Se content of various crops, but it consistently enhanced crop Se levels to varying degrees. Among the crops tested, soybean exhibited the highest Se content after exogenous supplementation, followed by wheat and then peanut, and the levels were 25.9, 323.2, and 32.9 times higher than those without Se spraying, respectively. It indicated that exogenous Se supplementation could significantly increase the Se content in soybean, wheat, and peanut, with soybean meeting the standard for Se-enriched agricultural products. After exogenous Se supplementation, the Se content in corn, sweet potato, grape, crisp pear, and apple ranged from 0.02 to 0.068 mg/kg. Although these levels did not meet the standard for Se-enriched agricultural products (0.10 – 0.15 mg/kg), they showed a clear increase compared with the control group. It demonstrates that exogenous Se supplementation can effectively enhance the Se content in crops, making it a viable method for improving crop Se levels.

Discussion and Conclusion

Using the five-point sampling method for measurement, the soil Se content in 18 townships of Xiayi County ranged from 0.08 to 0.34 mg/kg. Among these, Se-adequate areas, Se-deficient areas and severely Se-deficient areas accounted for 27.78%, 66.67%, and 0.055% of the total, respectively. In Ningling County, the soil Se content in 11 townships ranged from 0.13 to 0.23 mg/kg, and Se-adequate areas and Se-deficient areas comprised 18.18% and 81.82%, respectively. In Yongcheng City, the soil Se content in 4 townships ranged from 0.16 to 0.23 mg/kg, and Se-adequate areas and Se-deficient areas constituted 75.00% and 25.00%, respectively. The soil Se content in 33 townships across Xiayi County, Ningling County, and Yongcheng City ranges from 0.07 to 0.34 mg/kg. According to the industry standard GH/T 1135-2024 *Selenium-enriched Agricultural Products*, which specifies a Se content range of 0.10 – 0.15 mg/kg for Se-enriched agricultural products, the wheat Se levels in all 33 townships fail to meet this standard. It indicates that relying solely on soil Se supply is insufficient for crops to achieve the required Se levels for Se-enriched agricultural products. Exogenous Se supplementation could effectively enhance the Se content in soybean, wheat, peanut, corn, sweet potato, grape, crisp pear, and apple. Among these, soybean, wheat, and peanut exhibited the highest Se levels after supplementation, all exceeding 0.10 mg/kg and meeting the industry standard for Se-enriched agricultural products. It demonstrates that exogenous Se supplementation provides an effective approach for producing Se-enriched agricultural products.

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